9. NAVIGATION HAZARDS AT LOCKS

Flow conditions in lock approaches and lock chambers and gate sill elevations may present hazards to navigation traffic. Typical problems at specific projects related to currents and shoaling in lock approaches, surges in lock chambers and approaches related to filling and emptying operations, and tow squat are described in this section.

It should be noted that velocities and currents on some canalized rivers become too high for safe and efficient tow operation during floods. Navigation ceases at about the 10-yr recurrence interval flood on the Arkansas, Red, and Upper Mississippi Rivers. On the Arkansas, this is 250,000 cfs at Van Buren, 335,000 at Dardanelle, 350,000 at Little Rock and downstream. On the Red River, this is 125,000 cfs at Shreveport and 145,000 from Alexandria downstream, when mean channel velocity is in the order of 7 ft per sec and maximum velocities exceed 10 ft per sec. Lock and Dam 26 on the Mississippi River goes out of service at about 720,000 cfs.

Navigation locks are usually located in relatively straight reaches and in or near channel crossings in order to obtain adequate site distances in the upstream and downstream approaches. The best sites are cross sections that are somewhat wider than the average stream cross section because they provide sufficient width to compensate for obstruction of flow by the lock and spillway piers. Cross currents resulting from spillway operation (and power plant discharge if power is included in the project) and currents due to the natural channel configuration are important considerations in site selection.

Constriction of the natural channel by a lock usually results in cross currents in the upstream lock approach as flood flows move across the lock entance toward the spillway. Cross currents tend to develop near the upper end of the guard wall, Figure 9.1 The intensity of cross currents can be reduced by constructing ports in the guard wall, to pass flow intercepted by the guard wall, and by reducing velocities in the approach channel by using dikes to redistribute flow across the channel. Also, turbulence and vortices may occur in the immediate vicinity of the structure due to operation of the filling system.

In the downstream lock approach, undesirable and dangerous currents derive from three principal sources:

a. Spillway and power plant discharges.
b. Expansion eddies immediately downstream of the lock.
c. Currents from the lock emptying system.

Currents and velocities from a lock emptying system in the lower lock approach can be dangerous to tows approaching the lock, especially at medium- to high-lift locks. At such locks it may be desirable to locate the discharge manifold outside the lower lock approach, as at Greenup Lock, Figure 8.18b, and at Olmsted, discussed in Section 9.4.

Where releases from the dam expand downstream of a lock, sediment tends to move toward and into the lower lock approach, and the resulting deposition can be a significant problem.

9.1 Dardanelle Lock and Dam, Arkansas River

Model data for two alternative layouts of the power plant at Dardanelle Lock and Dam (lift 54 ft) illustrate the occurrence of cross currents in the upper lock approach with a ported upper guard wall, Figure 9.1. Ports in the upper guard wall reduce cross currents by permitting the flow intercepted by the lock to pass through the wall to the spillway. The effectiveness of ports in reducing cross currents depends on the number, size, and hydraulic efficiency of the ports. Franco (1976) suggested that, in general, the total cross-sectional area of port openings in the upper guard wall should be equivalent to the cross sectional area of the approach channel affected by the lock and lock walls and that the top of guard wall ports should be 4 to 6 ft below the bottom of a loaded tow to minimize pull of the tow toward the wall. Franco also recommended the channel bottom between the guard wall and bank be near or lower than the bottom of the ports to reduce velocities and prevent build up of head on the landside of the tow. When ports extend down to the stream bed, an alluvial bed should be protected against scour. Velocities in the upper approach in the Dardanelle model appeared to be low enough (1 to 2 ft/sec) and sufficiently well aligned with the lock so as to not interfere with tow movement.

Typical patterns and velocities in the lower Dardanelle approach are shown in Figure 9.2, based on model studies (U.S. Army, Corps of Engineers, 1960). Model studies indicated that ports in the lower guard wall were not effective in reducing eddy action downstream of the end of the wall. Based on model studies, all Arkansas River locks have ported upstream guard walls and solid downstream guard walls.

9.2 Lock and Dam 2, Red River

Lock and Dam 2 on the Red River (lift 24 ft) was completed in 1987. After completion, navigation conditions in the upstream lock approach were difficult at medium to high river flows when mean channel velocity was about 7 ft/sec and maximum velocities were in the order of 10 ft/sec. One of the alternative guide wall designs model tested is shown on Figure 9.3a. The upstream guide wall constructed is a 700-ft cellular structure with ports 35-ft wide (except for the most downstream port). When the project went into operation, flows were concentrated through the most downstream ports, and at some discharges, velocities were sufficiently high through the ports to pin tows against the wall. It was concluded that:

a. Flows through the ports should be redistributed to be more uniform.

b. Lateral flow distribution in the upstream reach of river should be altered to reduce the percent of total river flow entering the lock approach.

Robertson (1995) reported the following remedial measures were taken. A system of submerged dikes was installed upstream from the guide wall to force flow away from the lock side of the river; top of dikes was 14 ft below normal pool level. Flow conditions in the upstream approach improved immediately, and much less debris collected in front of the upper miter gates. In the next high-water season, river pilots reported it was much easier to enter and leave the lock with the dikes in place. The effect of such dikes is shown schematically in Figure 9.3b. Similar submerged dikes were installed initially at several Arkansas River locks having similar approach problems.

Unequal distribution of flow through ports in the guide wall was still a problem, however. Prototype measurements indicated that 60 percent of the flow entering that portion of river bounded by the guidewall passed through the downstream 25 percent of the wall. To redistribute the flow, concrete blocks were placed in the three full-sized ports at the downstream end of the wall, reducing flow through those ports about 50 percent. Approximately 38 percent of the entering flow now passes through the downstream 25 percent of the wall, and the current problem has been solved.

The Red River Waterway is discussed further in Appendix B.

9.3 Robert S. Kerr Lock and Dam, Arkansas River.

The Robert S. Kerr Lock has a 110- by 600-ft lock chamber on the left bank with a maximum lift of 48 ft and a four-unit powerhouse on the right bank. Embankments above maximum pool level connect the lock and dam to high ground on both banks. The ogee spillway has 18 tainter gates, each 44 ft high and 50 ft wide. General reach conditions prior to construction of the project and limits of the model are shown on Figure 9.4a. The structure layout and details are shown on Figure 9.4b; it will be noted that the 600-ft upper guide wall has 25-ft diameter sheet pile cells on 50-ft centers. Thus, the ports in the upper guide wall are 25 ft wide and 37 ft high.

Navigation conditions in the lock approaches were studied in a 1:120 fixed bed model. Model tests indicated (Franco and Glover, 1968) that with the original design:

a. Downbound tows approaching the lock would have difficulty because of high cross currents near the end of the upper guide wall caused by flow from the left overbank moving across the upper lock approach to the spillway, Figure 9.5.

b. Upbound tows approaching the lower guard wall would experience considerable difficulty in the lower approach due to the strong eddy that formed with the powerhouse in operation and no flow through the spillway. Velocities as high as 2.9 ft/sec cut across the navigation channel near the end of the lower guidewall, Figure 9.5. No problems should be encountred in the lower approach with the spillway in operation, Figure 9.5.

c. Tows passing under the bridge downstream of the lock would experience some difficulty.

Modifications (Plan C) in the model indicated that safe navigation conditions could be obtained in the upper approach by extending a fill from the left dam embankment at least 3000 ft upstream (top of the fill would be above the flow line for the maximum navigable discharge), Figure 9.6. The fill along the left side of the upstream lock approach forces cross currents from flow from the left overbank to move across the approach channel farther upstream where downbound tows can maintain sufficient speed and approach the upper guide wall without difficulty.

Eliminating ports in the upper guide wall (Plan C-1) increased size and intensity of the eddy along the riverside of the fill, Figure 9.6b. There was a tendency for tows to be moved away from the wall, making it difficult for them to align to enter the lock. With ports in the upper guide wall, tows had less difficulty in aligning for entrance than with a solid wall, but the capacity of the ports could be reduced significantly from that of the original design.

The adverse effects of the strong eddy in the lower lock approach with the powerhouse operating and no flow through the spillway was reduced by modifying the right bank downstream of the powerhouse and extending the lower guard wall with a 550-ft long rock dike. Currents and velocitiies with the powerplant operating with and without spillway discharge are shown in Figure 9.7. Extending the guide wall reduced the intensity of the eddy in the lower approach with the powerhouse in operation and gave tows entering and leaving the lock additional maneuvering area. The small eddy between the guide wall and the left bank did not appear to be of sufficient intensity to affect navigation.

9.4 Olmsted Locks and Dam, Ohio River

Olmsted Locks and Dam (lift 21 ft) is located on the lower Ohio River, 16.6 miles above the confluence of the Ohio and Mississippi Rivers. Tailwater at Olmsted Locks is not affected by a downstream navigation structure; open-river conditions prevail downstream. Tailwater elevation ranges widely and is influenced by Mississippi River backwater levels. There are two 110- by 1200-ft locks with a 21-ft lift, Figure 7.4. The emptying system consists of four wall culverts from the two locks (located in the land wall, middle wall, and river wall) emptying into a single outlet structure in the river, Figure 8.36.

A 1:25 scale model of the outlet for Olmsted Locks was used to investigate flow patterns, velocities and water levels in the vicinity of the outlet structure (Stockstill, 1992). The model reproduced the lock emptying system downstream of the emptying valves, approximately 1150 ft of the Ohio River, beginning 650 ft upstream of the outlet, and approximately 50 ft of the width of the river. Three steady state flow conditions were tested: land lock emptying; river lock emptying; and both locks emptying simultaneously. Unit river discharge was 57 cfs/ft, and the maximum outlet discharge was 10,500 cfs/lock (21,000 cfs with both locks emptying simultaneously). Depth-averaged velocities for the three conditions are shown in Figure 9.8. Worst-case conditions also were investigated, with a unit river discharge of 130 cfs/ft along the lock wall and both locks discharging for five hours (prototype). Observation of flow patterns indicated no adverse flow conditions in the vicinity of the outlet structure. Model studies to determine stability of riprap to be placed in the vicinity of the outlet structure, Figure 9.9a, indicated that material with a D_{50} size of 24 inches and the gradation shown in Figure 9.9b would be stable for these extreme flow conditions.

The Olmsted project is discussed further in sections 7-2 and 8-22..

9.5 Canal surge and tow squat

Temporary Lock 52, Ohio River. An investigation was made in 1985 of navigation conditions at the temporary 110- by 1200-ft lock, Figure 9.10, constructed at Locks and Dam 52, Ohio River, in 1969 (Maynord, 1987). The new lock is landward of an older 600-ft lock, and normal lock lift is 12 ft. This temporary lock operated for many years without a draft restriction and without damage to the lower miter gate sill. However, there is only 11 ft of depth over the lower sill, and one pilot, either pushing a heavily loaded tow too fast or with excessive acceleration while over the sill, damaged the lower sill and put the lock out of operation. Following the accident, a draft restriction was strictly enforced. When the gage falls below 10 ft (12 ft of depth over the sill), tows with over 9.25 ft of draft are required to use the 600-ft lock. Drafts of all barges were measured, which increased lockage time and was time consuming. Operators felt that a speed restriction combined with a draft restriction might be more effective.

Early in the study, a limited prototype investigation was made to observe tow movement and to measure speed and squat. Maynord (1987) reports the following observations:

- Towboats operating on the lower Ohio River have a wide range of power, up to 8500 horsepower; larger boats had Kort nozzles with a steering rudder behind the wheel and two backing (flanking) rudders in front. Smaller boats had similar rudders, but open wheels (no Kort nozzles). Connections between the towboat and tow were made in different ways, and there was no consistency in arrangement of empty and loaded barges.
- All pilots used very low headway entering and leaving the lock, with power usually set at 100-200 wheel rpms. Pilots of larger boats cut the power off while the boat was over the lock sill. Very little and very infrequent rudder was applied once the tow was lined up with the lock and sheltered by the approach walls.
- Squat was a maximum (up to 0.8 ft) when the towboat was accelerating or decelerating. While under way at constant speed, squat ranged from 0.1 to 0.65 ft. Squat was less than 0.1 ft when coasting.
- Tows entering the lock from downstream maneuvered slowly until the bow was in the confined section and the tow was aligned with the walls. Tows then came ahead with significant speed.
- In the past, the downsteam culvert valve was often closed after the lower pool elevation was reached in the lock, but operators are now leaving the valve open while tows move in and out of the lock.
- Operators generally lock three tows up and three tows down when tows are waiting.
- Operators stated that some towboats have drafts in excess of 9 ft and that tows often have towboats too small for the load being pushed.

Tow squat is the vertical drop of the tow due to motion, measured from the still water level. Maynord (1987) describes four phenomena causing squat as follows:

a. Displacement squat occurs in confined waterways when water adjacent to the tow is set in motion by displacement of the tow. To maintain the same total energy, the water surface drops an amount equivalent to the kinetic energy of the moving water. It is related to tow speed, ratio of tow cross-sectional area to channel cross-sectional area, and depth of water. Propeller speed is unimportant.

b. Piston squat occurs in locks where the channel is blocked at one end; it is significantly different for tows entering and exiting a lock, Figure 9.11a. Entering tows pile up water in front of the tow, giving them extra depth, and piston squat does not occur. For tows leaving a lock, the volume behind the tow can increase at a greater rate than the return flow under and around the tow, and water depth behind the tow can decrease causing squat. This is not related to propeller movement.

c. Propeller squat is caused by the ability of the towboat to pump water from beneath itself faster than it can be replaced. It is significant only in shallow water and is increased by barges upstream which can block the supply of water to the propellers in a confined waterway such as a lock.

d. Moment squat is caused by the offset between the force produced by the propellers and the force at the connection with the barges, Figure 9.11b. It is greatest with empty barges and produces a moment that tends to force the rear of the towboat down.

Maynord (1987) reported that model studies using both self-propelled tows and a towing apparatus showed that:

a. Squat for entering tows is caused by different parameters than those causing squat for exiting tows. Maximum squat for almost every self-propelled test (entering and exiting) was at the stern of the towboat.

b. For entering tows, tow speed is not important, and displacement, piston, and moment squat were either small or inapplicable. Propeller squat is the primary mechanism producing squat.

c. For exiting loaded tows, propeller squat is an important mechanism. In acceleration tests, during which all tows approached the sill at the same speed, there was increased squat for increased propeller speed.

d. Entry speed can be very irregular due to translation waves from tows moving from unrestricted water into confined water.

e. Unloaded exiting tows can have enough squat to strike the lower sill when operating at high propeller and tow speed and low clearance between tow and sill.

f. Emptying valves should remain open during tow entry and exit. Squat is considerably less with the valves open for equal tow speeds, Figure 9.12a and 9.12b.

g. Large towboats are most likely to strike the lower sill because they have the greatest draft and the greatest potential for producing propeller squat. Small towboats may be susceptible to striking the lower sill because they may have to use increased power while in the vicinity of the sill.

Maynord (1987) pointed out that the primary weakness of the model study was that only one towboat and pilot were used and that the squat/propeller speed/draft relationships for the model towboat cannot be strictly applied to all prototypes. However, identifying propeller speed as the primary variable controlling tow squat in locks can be useful in solving prototype problems.

Bay Springs Lock and Dam. Bay Springs Lock and Dam is the uppermost navigation structure on the Tennessee-Tombigbee Waterway, connecting the two rivers. It is located at the southern end of the Divide Section of the waterway and creates a pool extending through the divide cut to Pickwick Lake on the Tennessee River. The Bay Springs project includes a rock-fill dam, a 110- by 600-ft lock, and a canal extending downstream, Figure 9.13. Bay Springs Lock has a normal lift of 84 ft; maximum lift of 92 ft; and minimum lift of 78-ft. The canal has a 300-ft base width, depth of 13 ft, and is excavated in rock for approximately one mile downstream from the lock, with side slopes of 4V on 1H.

Surge conditions in the canal were investigated in a 1:80 undistorted model (Tate, 1978). A tow consisting of nine barges loaded to 9-ft draft (prototype) was used with a motorized towboat. Design of the original outlet diffuser system is shown in Figure 9.14a. A 1-minute valve opening and 11.9-minute emptying time were used in initial model tests, and this operation produced a 1.9-ft high translatory wave with a steepening leading face which transformed into an undular wave with crests increasing to 2.6 ft above normal pool. Forces measured on tows moored downstream indicated conditions would be very hazardous for navigation. Observations indicated that a tow moving upstream at approach speeds of 2.7 to 4 miles per hr would be transported 60 to 120 ft downstream by the lock release even with increased power applied.

Longer valve opening times were tested, and slower valve opening times significantly reduced wave height and maximum forces exerted on moored tows. A 2-min valve opening time decreased forces approximately 33 percent; valve opening times of 4 and 8 minutes were only slightly better. It was concluded (Tate, 1978) that the undular wave did not form in the model with valve opening times longer than one minute; that the slope of the water surface in the canal rather than wave height was a good indicator of forces on a tow; and that slope of the water surface was a function of speed of valve opening.

The diffuser design was modified, and the design shown in Figure 9.14b was tested. The lock and canal were realigned to place the lock guide wall on the right bank of the canal, permitting tows to use the full width of the canal when maneuvering to enter the lock. The modified design provided a uniform discharge across the width of the canal. Maximum force on a moored tow was reduced from 170 tons to about 40 tons with a 1-min valve opening time and to about 20 tons with a 2-min valve opening time

Studies of the relationship between filling and emptying times for longitudinal floor culvert systems in lock models and prototype indicate that prototype locks will empty about 18 percent faster than the model. The stage-time relation for Bay Springs was adjusted and tested in the model. The expected prototype surge with valve-opening times of 1 and 2 minutes is shown in Figure 9.15. With the 2-min valve opening time, the maximum rate of rise of the water surface was 0.06 ft per sec with a maximum surge height of 2.5 ft above normal pool. Forces on tows did not exceed 36 tons and maintained a uniform rate of loading of approximately one ton per sec.

Based on model tests (Ables 1978), the recommended emptying times for Bay Springs Lock are:

	Filling	Emptying
Valve operating time	1 min	2 min
Model operation	10.5 min	13.3 min
Prototype (estimated)	8.6 min	10.9 min

Details of the emptying manifolds (Ables, 1978) are shown in Figure 9.16.

The intake design with invert at elevation 352, Figure 9.17, was satisfactory and vortex-free. Tests were made also on a 1:25 scale model with the invert of the intake ports raised 8 ft, but the higher level resulted in the formation of persistent swirls over the intake ports. Based on experience, persistent swirls in a 1:25 scale model indicates vortices will occur in the prototype (Ables, 1978).

When too much air is admitted to the filling culverts at the control valves, air pockets form that cause surges when they are released into the lock chamber, and it is, therefore, important to control the admission of air to ensure that only as much air is admitted as can be entrained as small bubbles. The filling valves at Bay Springs Lock were lowered to elevation 304 to obtain desired pressure conditions on the roof of the culvert immediately downstream of the valves during filling operation when cavitation could occur, and controlled air-vent slots in the culvert roof 7 ft downstream of the valve admit air to minimize cavitation. The qualitative effect of air venting is shown on Figure 9.18. Final adjustment of the air vents must be made in the prototype.

Lock and Dam 17, Verdigris River (Choteau Lock and Dam, Arkansas River Navigation Project). Dam 17 is located in the Verdigris River, and Lock 17 is located in a canal about 3400 ft east of the river, Figure 9.19. Normal lift is 21 ft; maximum lift is 24 ft. The upstream canal approach to the lock is 150 ft wide and 9 ft deep for about a mile, Figure 9.19 (Huval, 1980). There are wider reaches, with 300-ft bottom width at the junction of the canal and the Verdigris River and just upstream of the lock to aid navigation and reduce surge effects.

Most towboats operating on the Verdigris at the time this study was made were of the 2000 to 4200 horsepower class, and most tows were about 105 ft wide, with 7 to 8.5 ft draft and about 600 ft long. Such tows occupy a major part of the canal cross section, Figure 9.20, and this causes tows to squat as much as 1.5 to 2 ft below static floating position, depending on tow size and speed. Groundings occurred for both upbound and downbound tows, particularly in the transition reaches. The squat problem worsened when the lock chamber was filled when a downbound tow was in the approach channel. Field tests indicated as much as 1.3 ft of drawdown one mile upstream from the lock (Huval, 1980).

A mathematical model was used to determine lock filling surge heights along the canal for 15 different canal configurations. Results for the maximum surge amplitude near the end of the transition immediately above the lock are summarized in Figure 9.21. For the maximum surge amplitude near the end of the transition immediately above the lock, surge amplitude decreases with increasing canal cross section, and the rate of decrease is greater due to canal widening than to canal deepening. However, clearance under the tow (deepening) is critical at the time of maximum surge.

Tow squat increases as the square of tow speed, and laboratory and field tests indicate that self-propelled tows cannot exceed V_l (Schijf limiting speed) and usually operate at from 50 to 90 percent V_l, Figure 9.22a. The data indicate increasing canal width (and maintaining constant base depth) will not lessen grounding problems for tows proceeding at the highest possible speed

($0.9\ V_l$). It was concluded that widening the canal without deepening probably would aggravate the grounding problem.

The effect of increasing canal depth on tow squat (and maintaining constant base width) is shown in Figure 9.22b. The data indicate that squat at limiting tow speed increases more rapidly with increased depth than with widening. Data in Figure 9.23 indicate that relative squat increases more rapidly by deepening the canal than by widening; however, the increase in squat is small and less than the increase in canal depth. Thus, it is more advantageous to deepen the canal than to widen it for a given increase in cross-sectional area.

It was concluded that a 12- by 300-ft canal cross section would eliminate the possibility of grounding, would significantly improve limiting tow speeds, probably reduce transit times through the canal, and improve navigation conditions.

9.6 Shoaling

In selecting sites for navigation locks and dams on alluvial streams, consideration must be given to sediment transport and deposition patterns. Shoaling in the lower lock approach, if not remedied, can be a serious and continuing problem, expensive for tow operators in lost time and requiring periodic dredging. At sites in bends there is a natural tendency for sediment to be moved away from the concave bank, but special training structures may be required at sites in relatively straight reaches.

The tendency for shoaling (deposition of sediment) in the upstream lock approach can be reduced by constructing ports in the upstream guide wall, with the top of ports below the bottom of the tow and bottom velocities through the ports sufficiently high. Shoaling in the lower approach is a more difficult problem. Sediment moves downstream along the lower lock wall (on the spillway side) and is carried into the lower lock approach as the flow expands downstream at the end of the guard wall and by spillway and power plant flows. Some deposition also occurs due to eddy action in the approach.

Model studies indicated that a properly designed wing dike, extending downstream from the riverward wall for 400 to 600 ft and angled riverward at about 10 degrees, would reduce deposition in the Dardanelle lower lock approach (Figure 9.24 and 9.25). The wing dike, with a top elevation about 2 ft above normal lower pool, permits relatively sediment-free surface flow to pass over the dike while blocking passage of the more heavily sediment-laden bottom currents. Such structures have been effective in reducing dredging requirements at Arkansas River locks, (Franco, 1976).

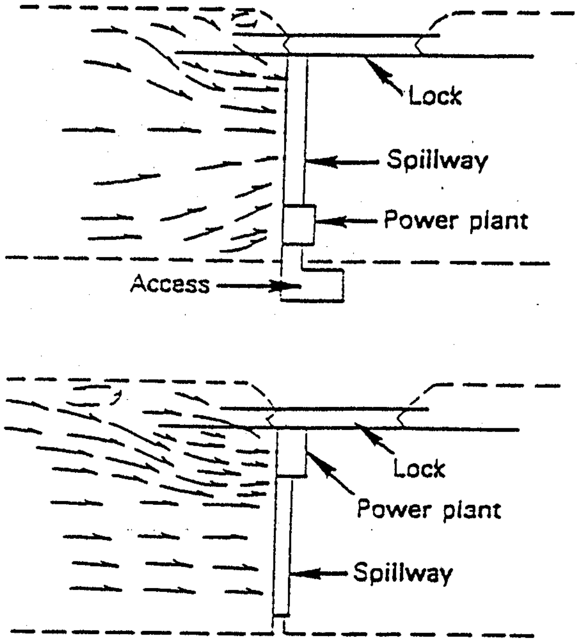


Figure 9.1. Flow patterns in upstream lock approach, Dardanelle Lock and Dam, Arkansas River. (Spillway discharge: 200,000 cfs; power plant discharge: 36,000 cfs.) (Corps of Engineers, 1960).

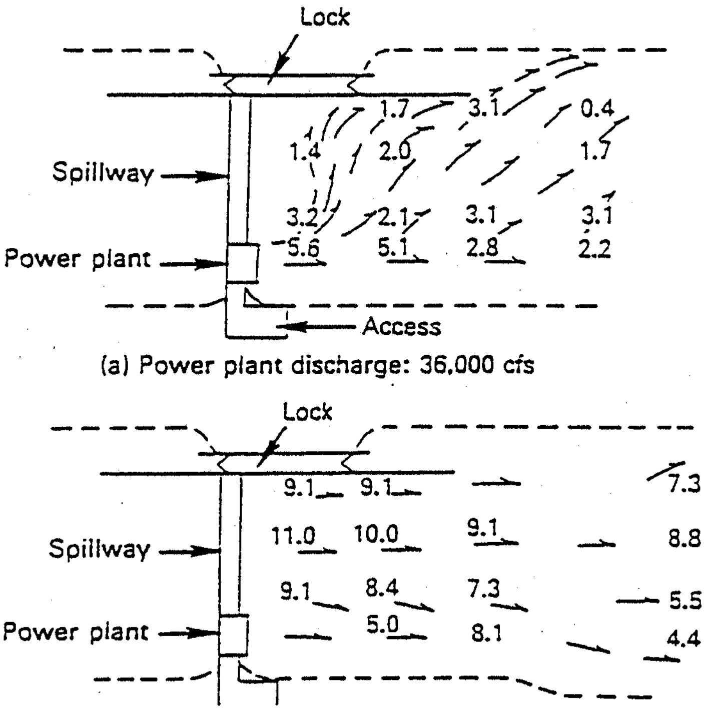
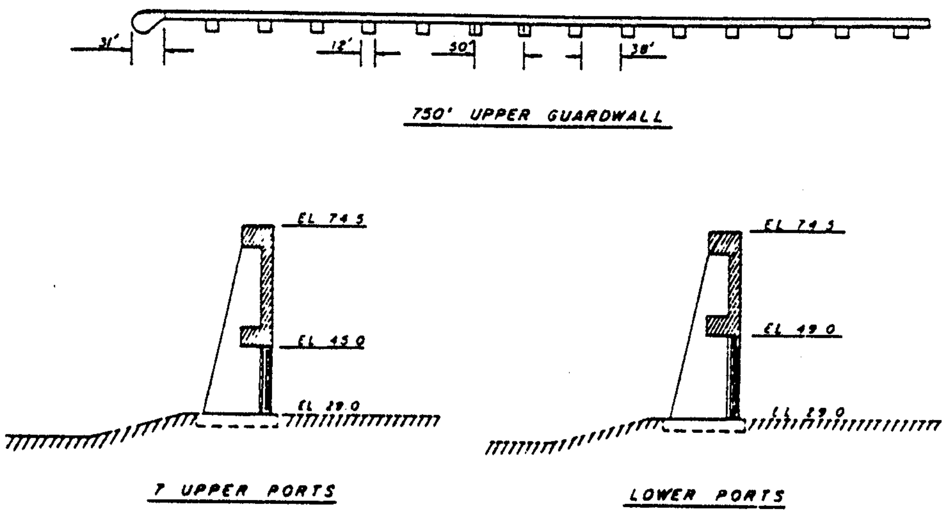
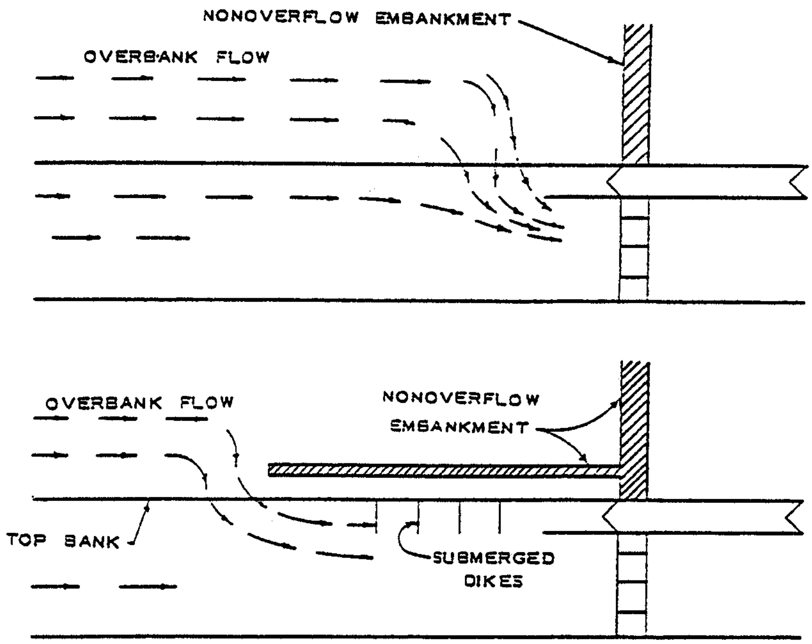


Figure 9.2. Flow patterns and velocities downstream of Dardanelle Lock and Dam, Arkansas River. (Corps of Engineers, 1960)



a. Upper guard wall (Shows and Franco, 1979).



b. Effects of overbank flow and submerged dikes (Corps of Engineers, 1980).

Figure 9.3. Upstream lock approach, Lock and Dam 2, Red River.

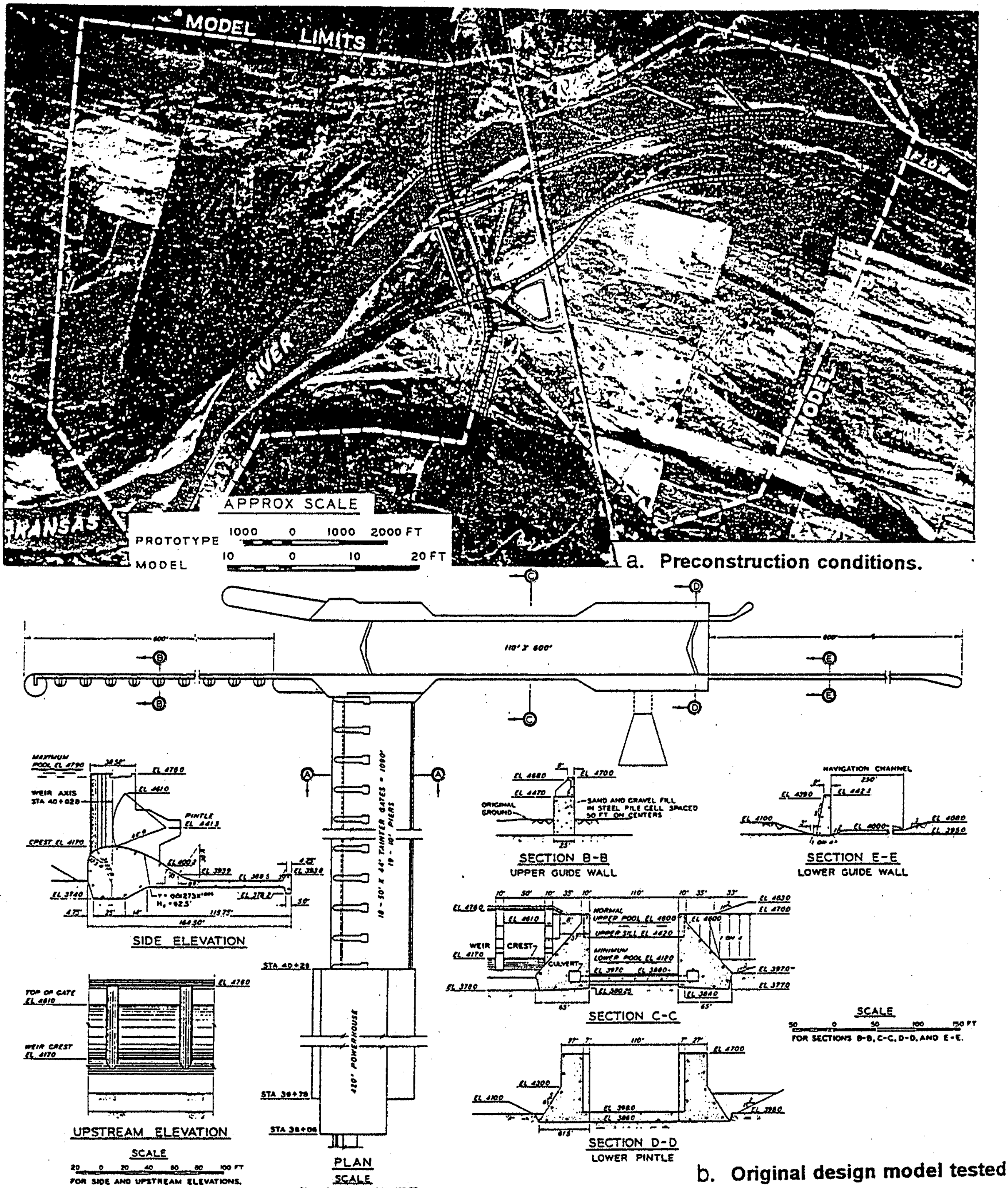
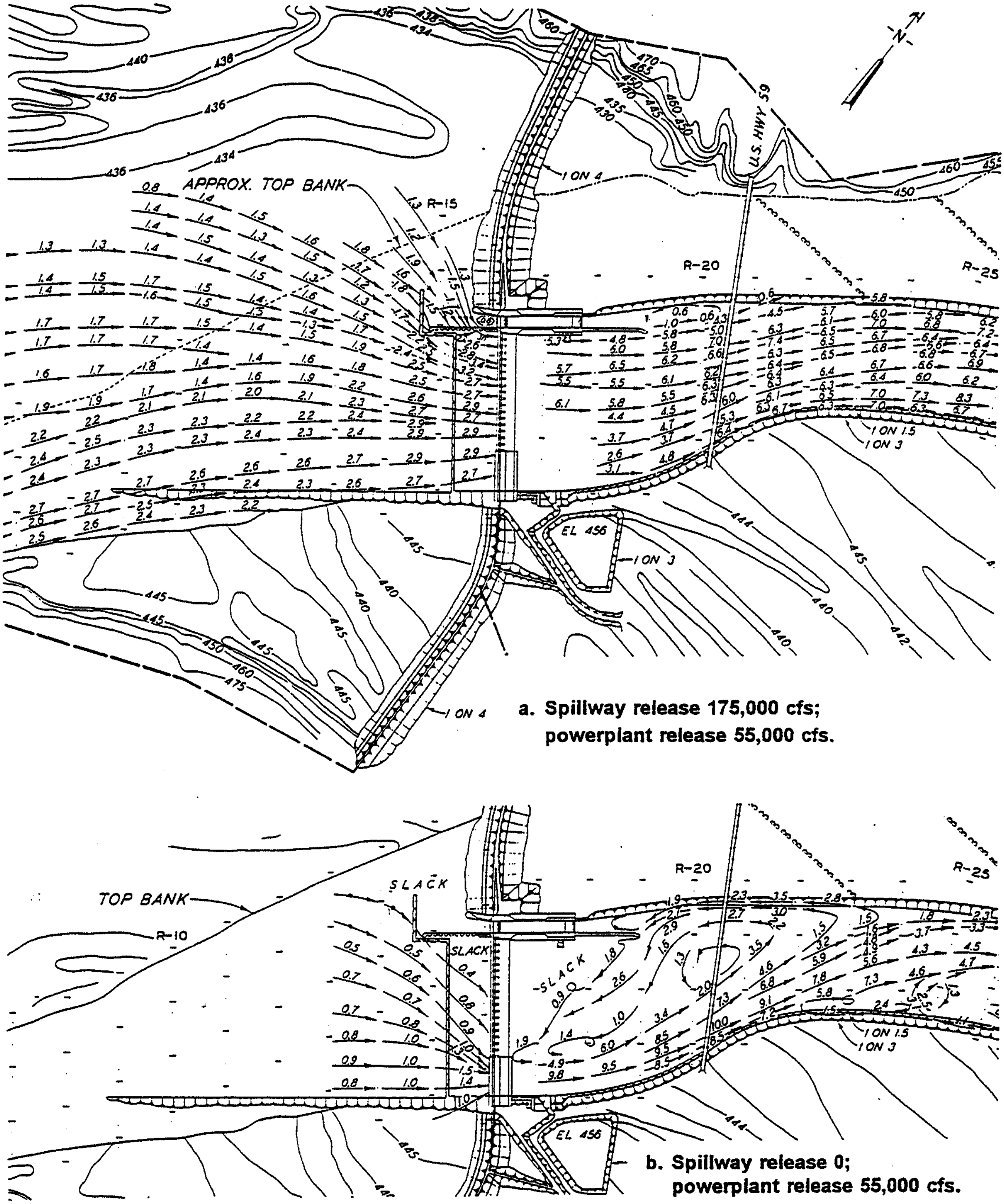


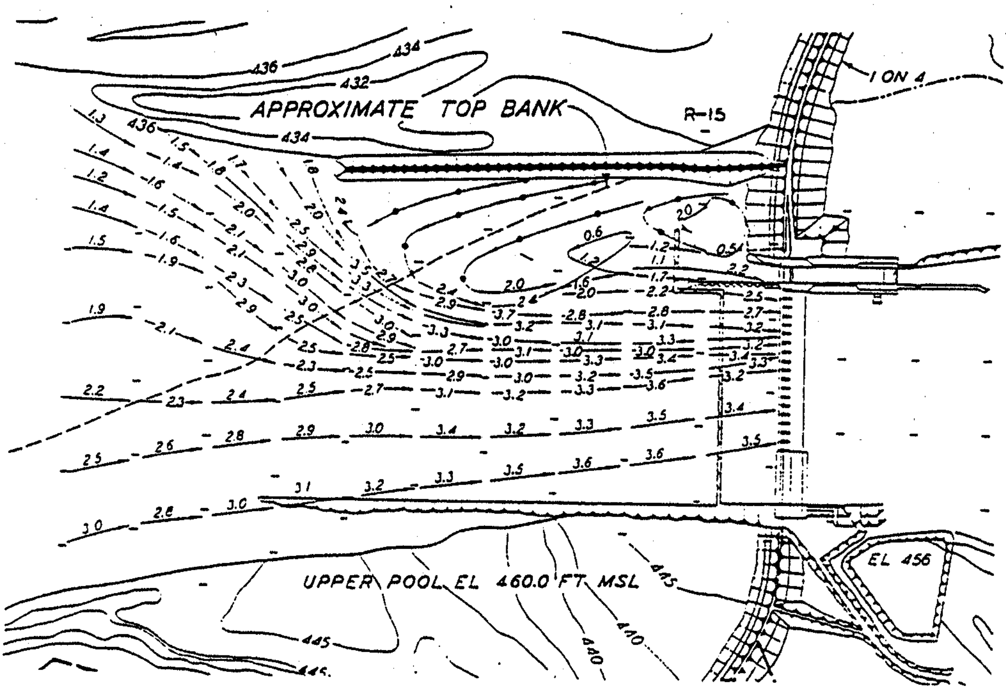
Figure 9.4. Robert S. Kerr Lock and Dam, Arkansas River (Franco and Glover, 1968).



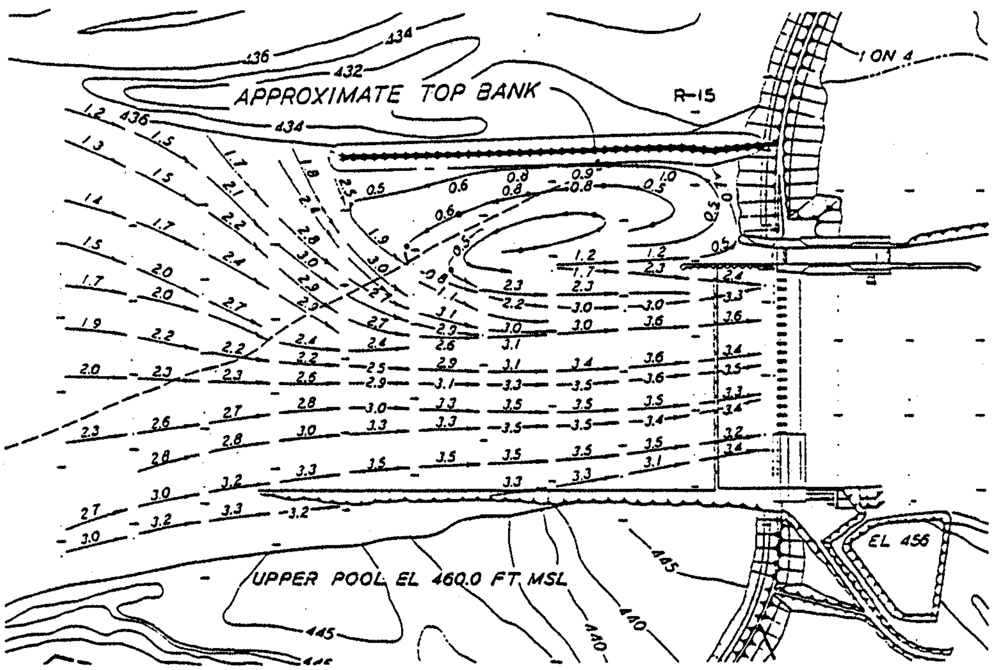
a. Spillway release 175,000 cfs; powerplant release 55,000 cfs.

b. Spillway release 0; powerplant release 55,000 cfs.

Figure 9.5. Velocities and currents, original design, Robert S. Kerr Lock and Dam, Arkansas River (Franco and Glover, 1968).

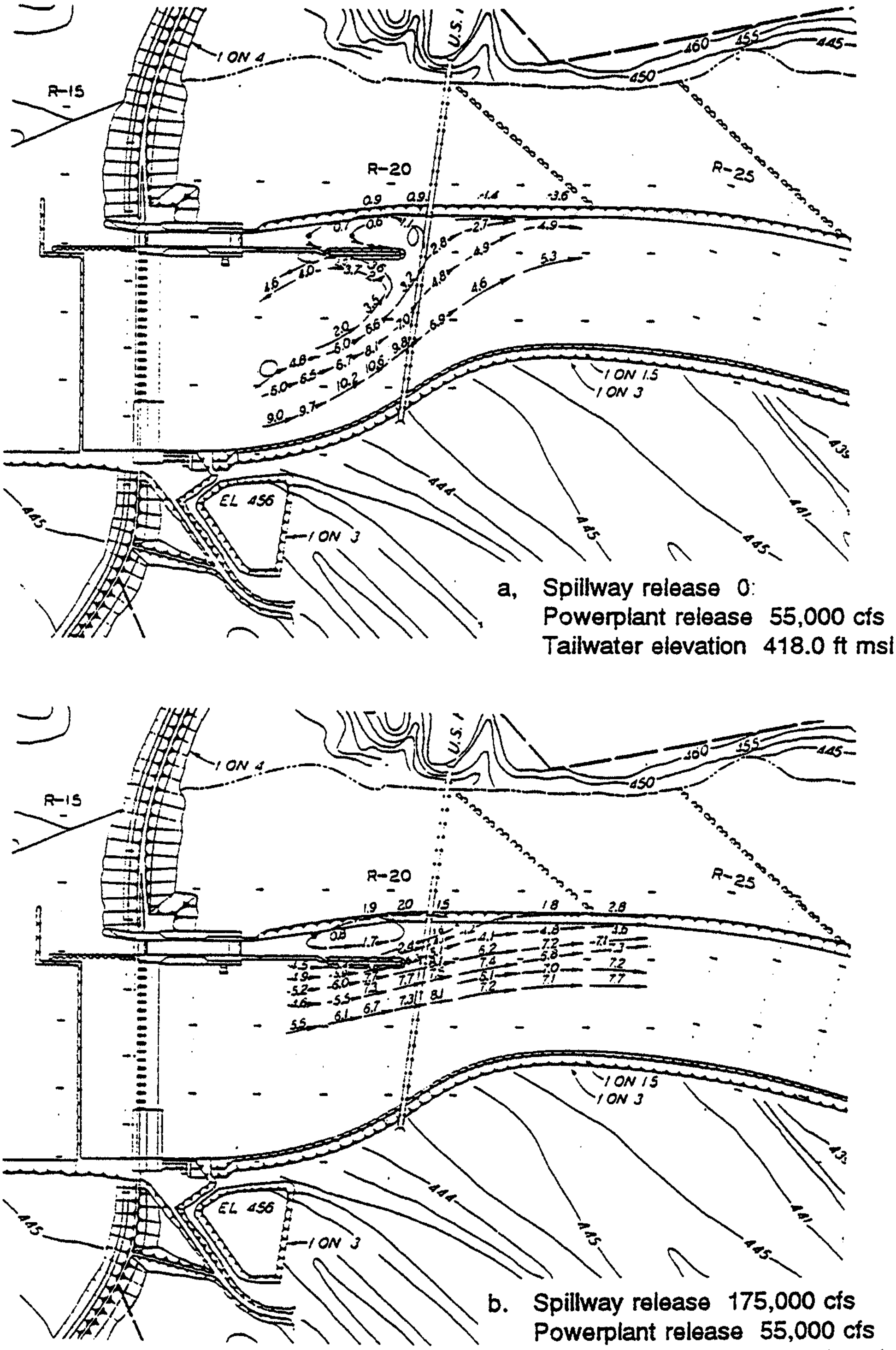


a. Plan C - 3000-ft left bank embankment; ports in upper guide wall.



b. Plan C1 - 3000-ft left embankment; no ports in upper guide wall.

Figure 9.6. Velocities and currents, Plans C and C1, Robert S. Kerr Lock and Dam, Arkansas River. Spillway release 175,000 cfs; powerplant release 55,000 cfs. (Franco and Glover, 1968).



a, Spillway release 0
Powerplant release 55,000 cfs
Tailwater elevation 418.0 ft msl

b. Spillway release 175,000 cfs
Powerplant release 55,000 cfs
Tailwater elevation 431.2 ft msl

Figure 9.7. Velocities and currents, lower lock approach, with modifications to improve navigation conditions, Robert S. Kerr Lock and Dam, Arkansas River (Franco and Glover, 1968).

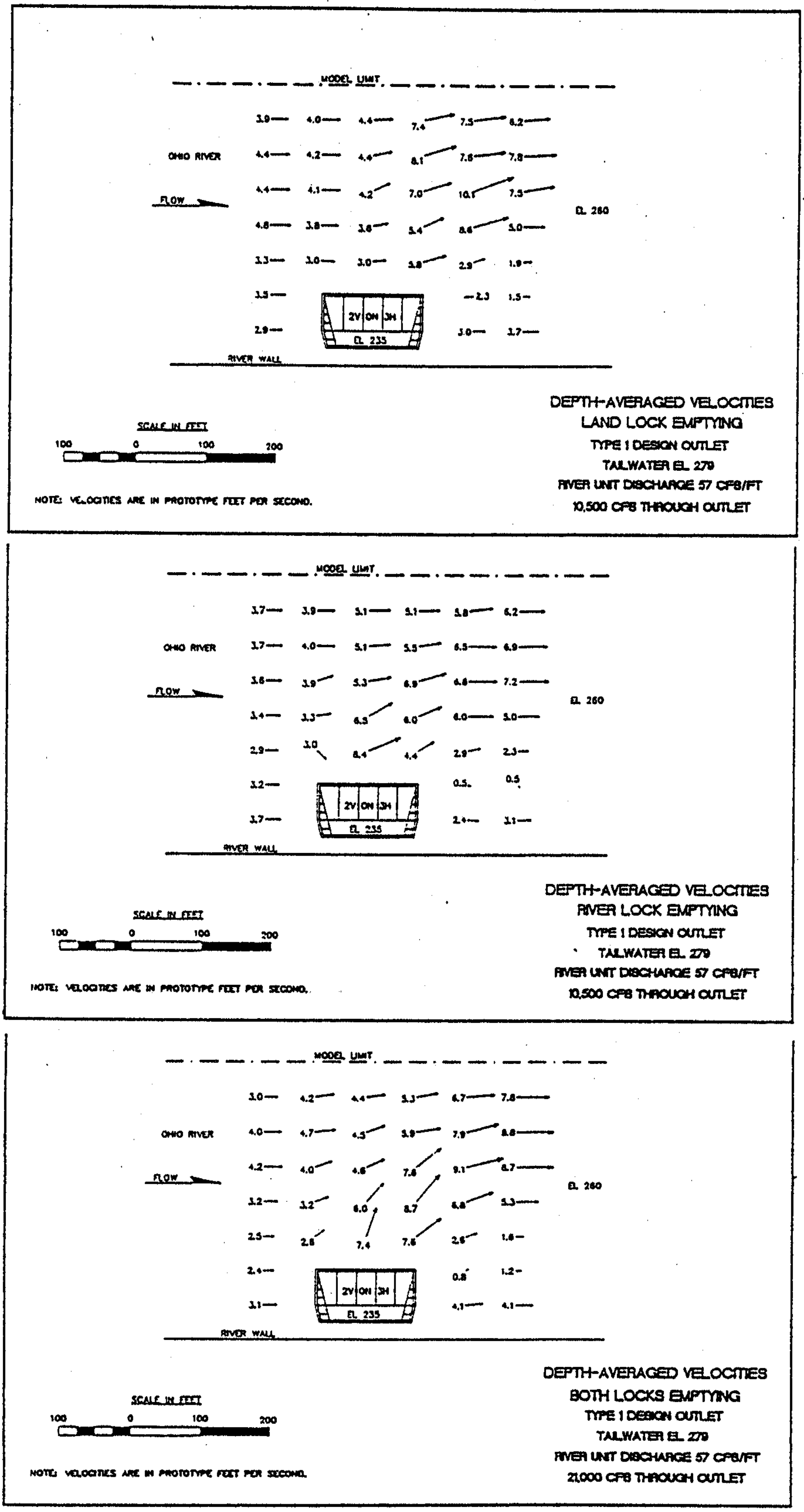
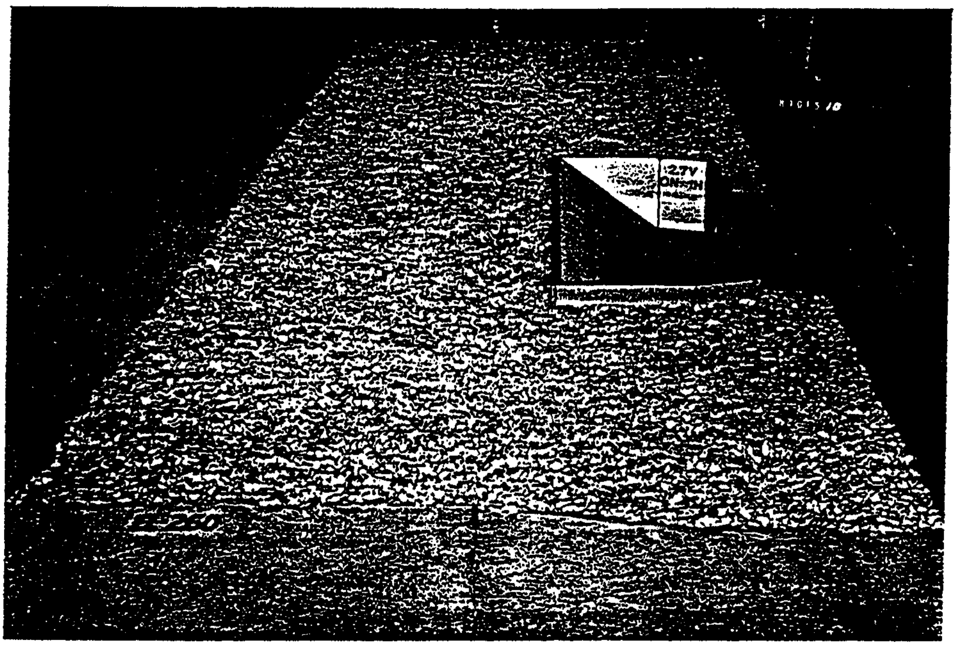
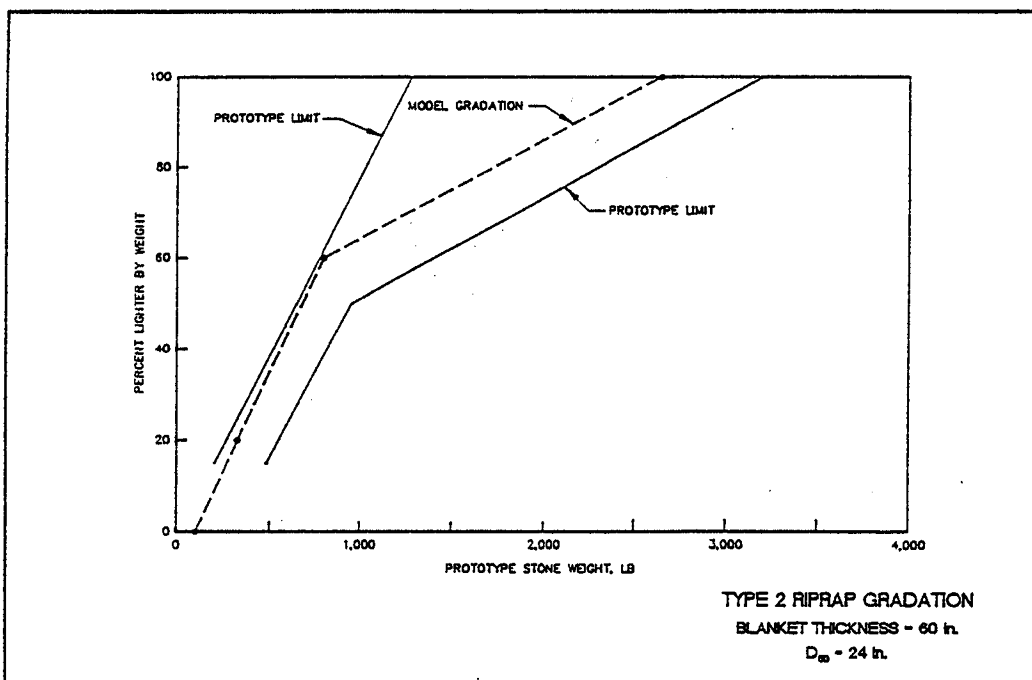


Figure 9.8. Depth-averaged velocities, river outlet, Olmsted Lock and Dam, Ohio River (Stockstill, 1992).

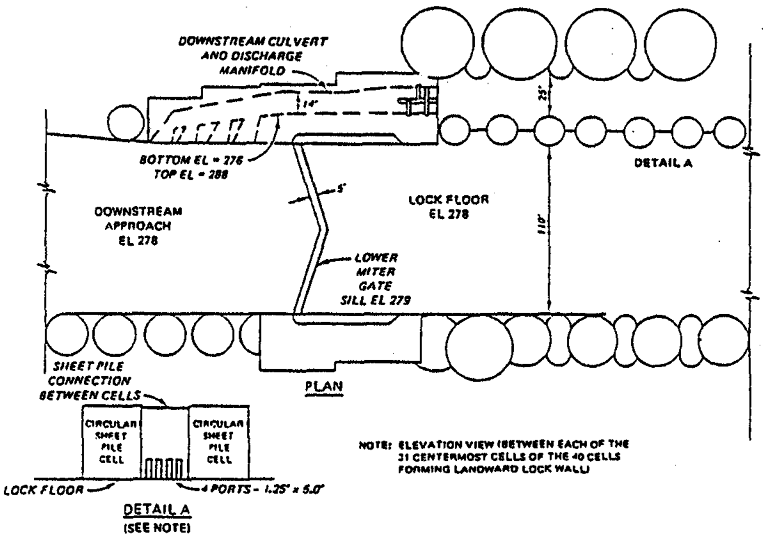


a. Riprap blanket at outlet.

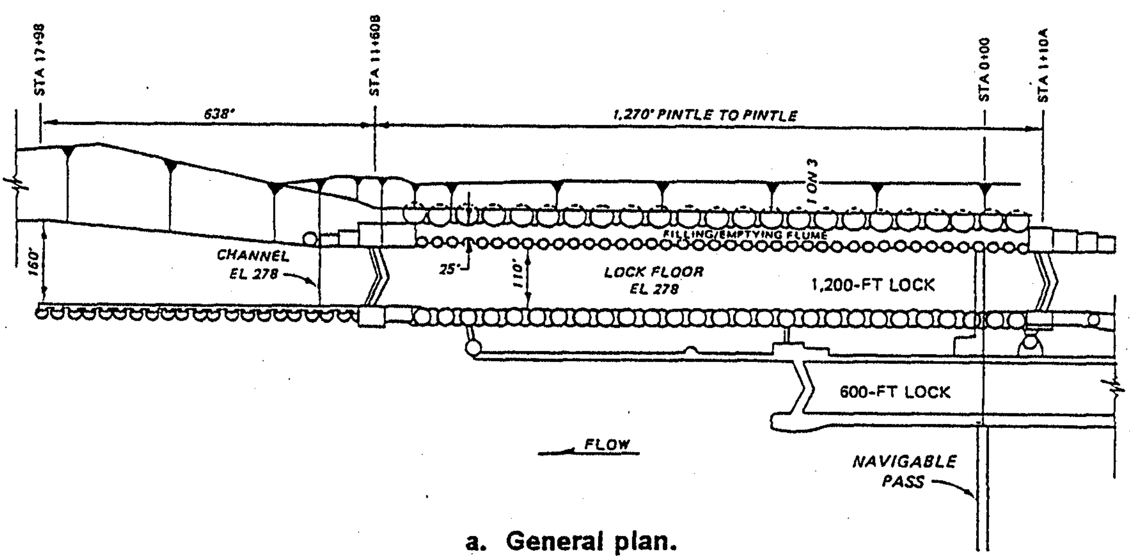


b. Gradation of Type 2 riprap.

Figure 9.9. Riprap protection at river outlet, Olmsted Lock and Dam, Ohio River (Stockstill, 1992).

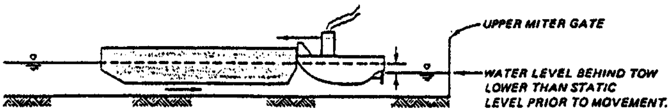


b. Details of lock and discharge culvert.

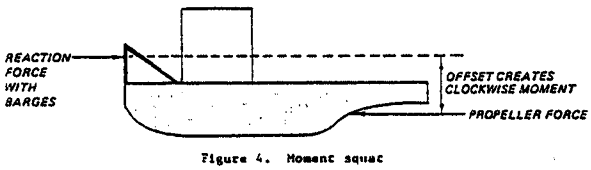


a. General plan.

Figure 9.10. Temporary Lock 52, Ohio River
(Maynord, 1987).

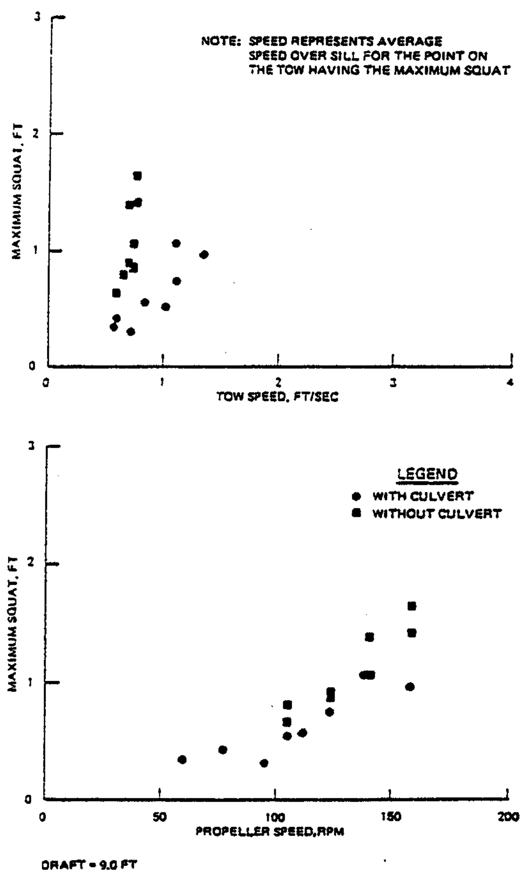


a. Piston squat.



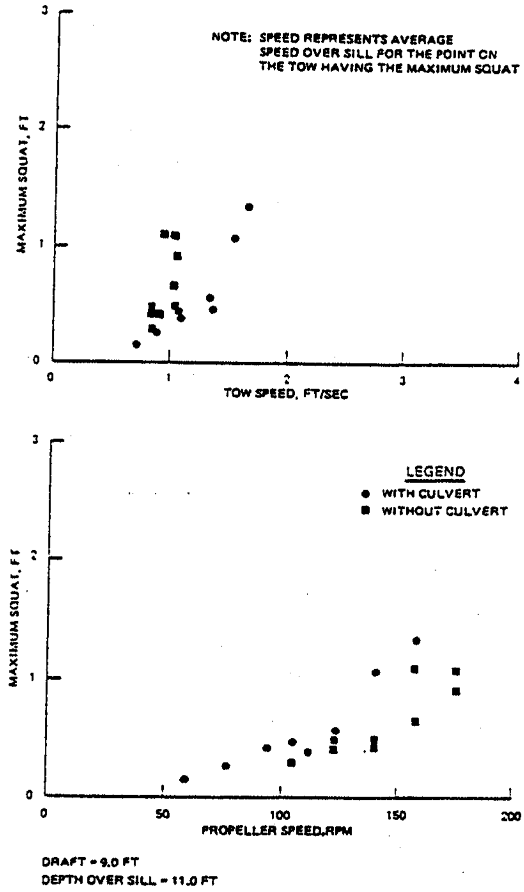
b. Moment squat.

Figure 9.11. Squat mechanisms (Maynord, 1987).



a. Entering tows.

Figure 9.12. Comparison of squat for entering and exiting tows with and without emptying culvert open (Maynord, 1987).



b. Exiting tows.

Figure 9.12. Comparison of squat for entering and exiting tows with and without emptying culvert open (Maynord, 1987).

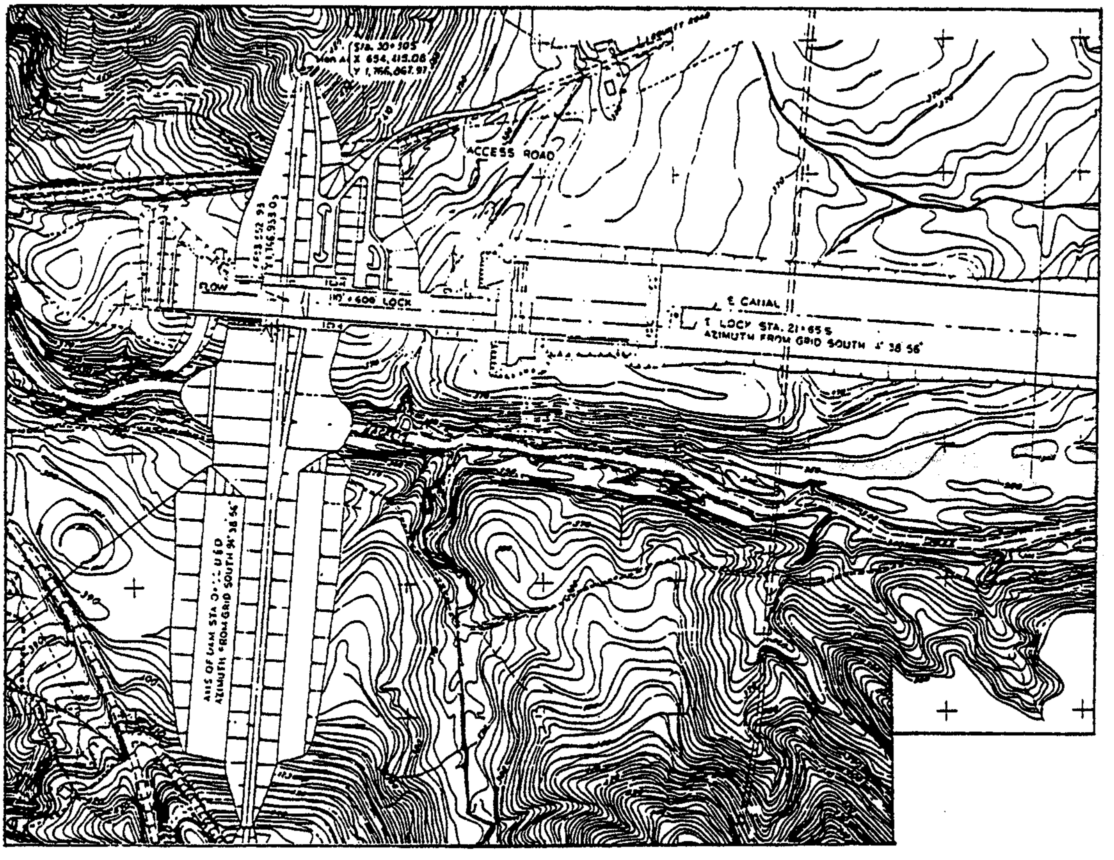
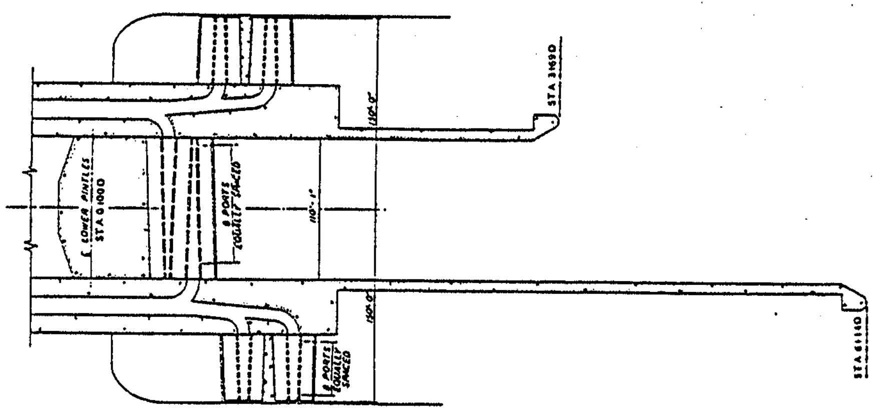
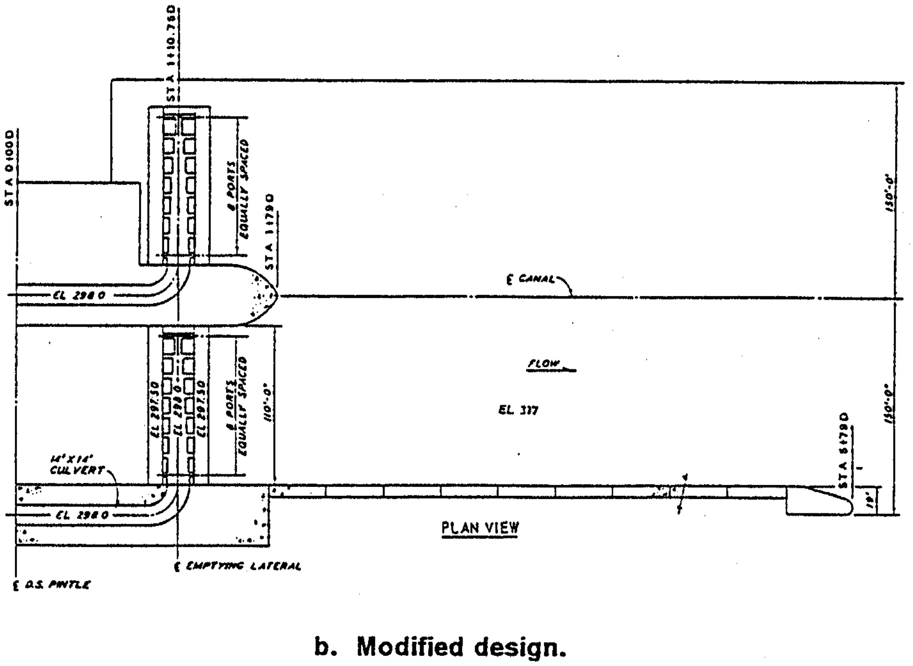


Figure 9.13. Bay Springs Lock and Dam, Tennessee-Tombigbee Waterway, dam, lock and canal alignment (Tate, 1978).

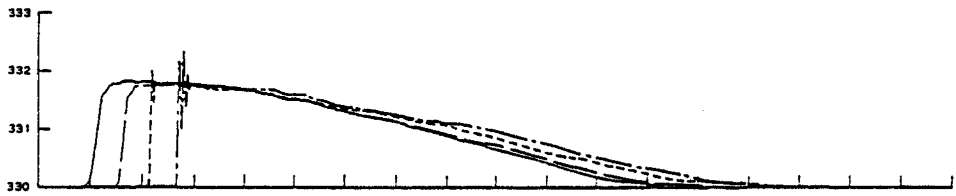


a. Original design.

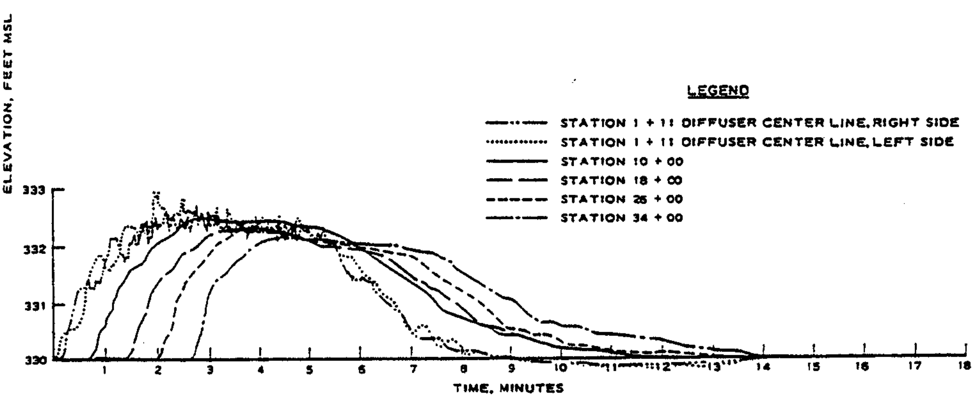


b. Modified design.

Figure 9.14. Outlet diffusers and lower lock approach, Bay Springs Lock (Tate, 1978).



a. 1-minute valve opening time.



b. 2-minute valve opening time.

Figure 9.15. Expected prototype surge, no tow, Bay Springs Lock (Tate, 1978).

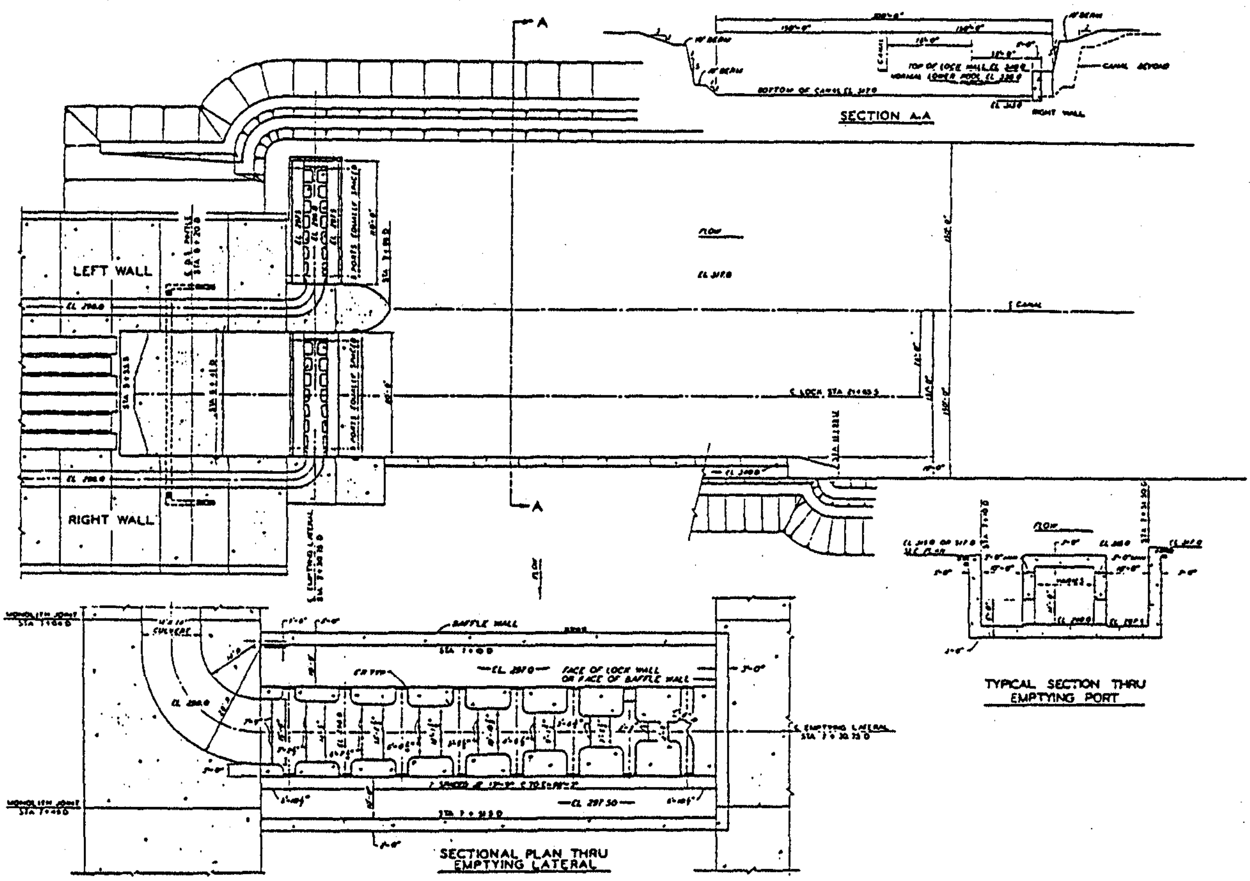
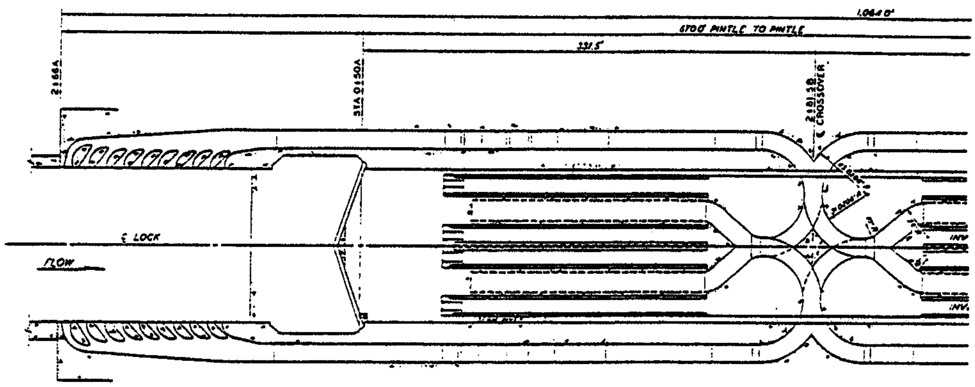
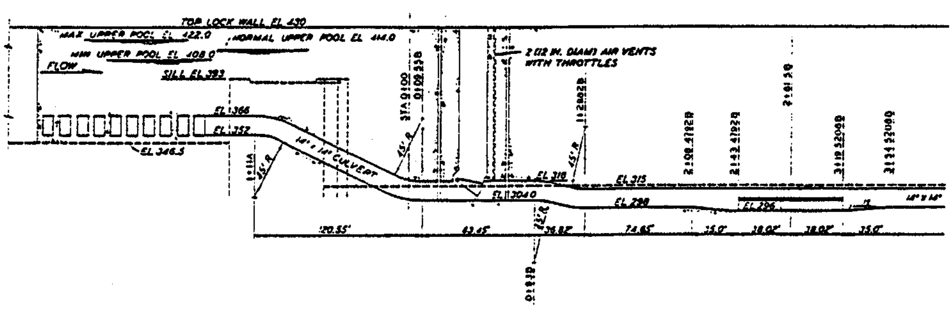


Figure 9.16. Emptying system, Bay Springs Lock (Ables, 1978).



a. Plan.



b. Left culvert elevation.

9.17. Intake system, Bay Springs Lock
(Abies, 1978).

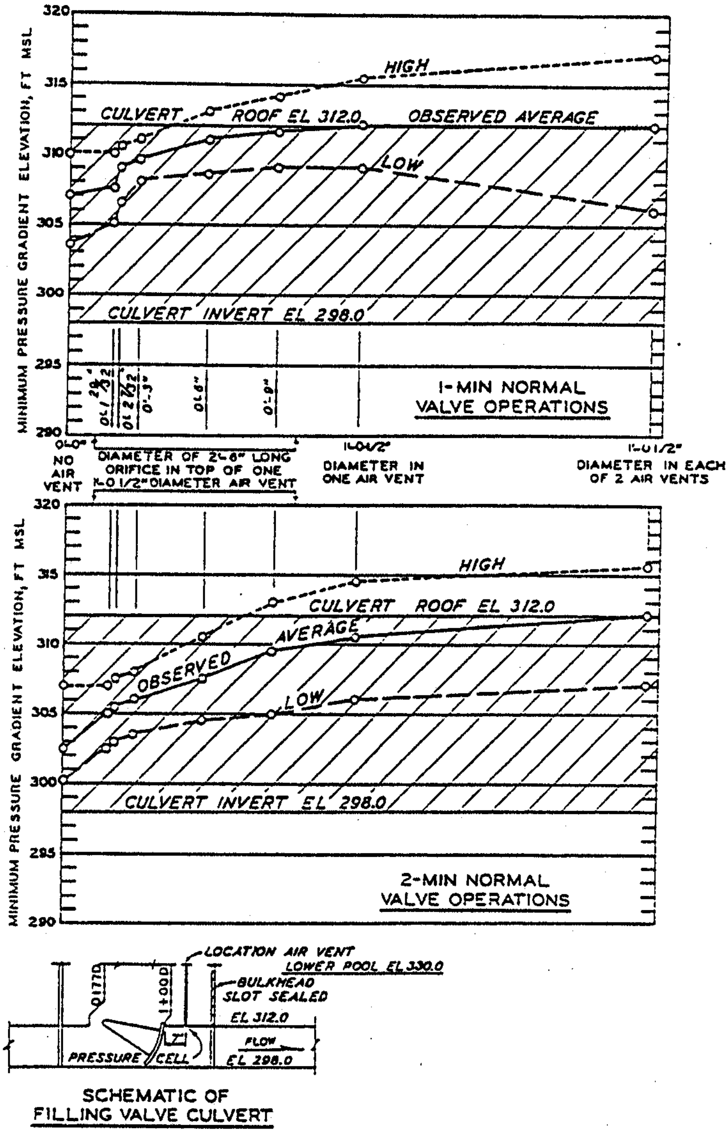
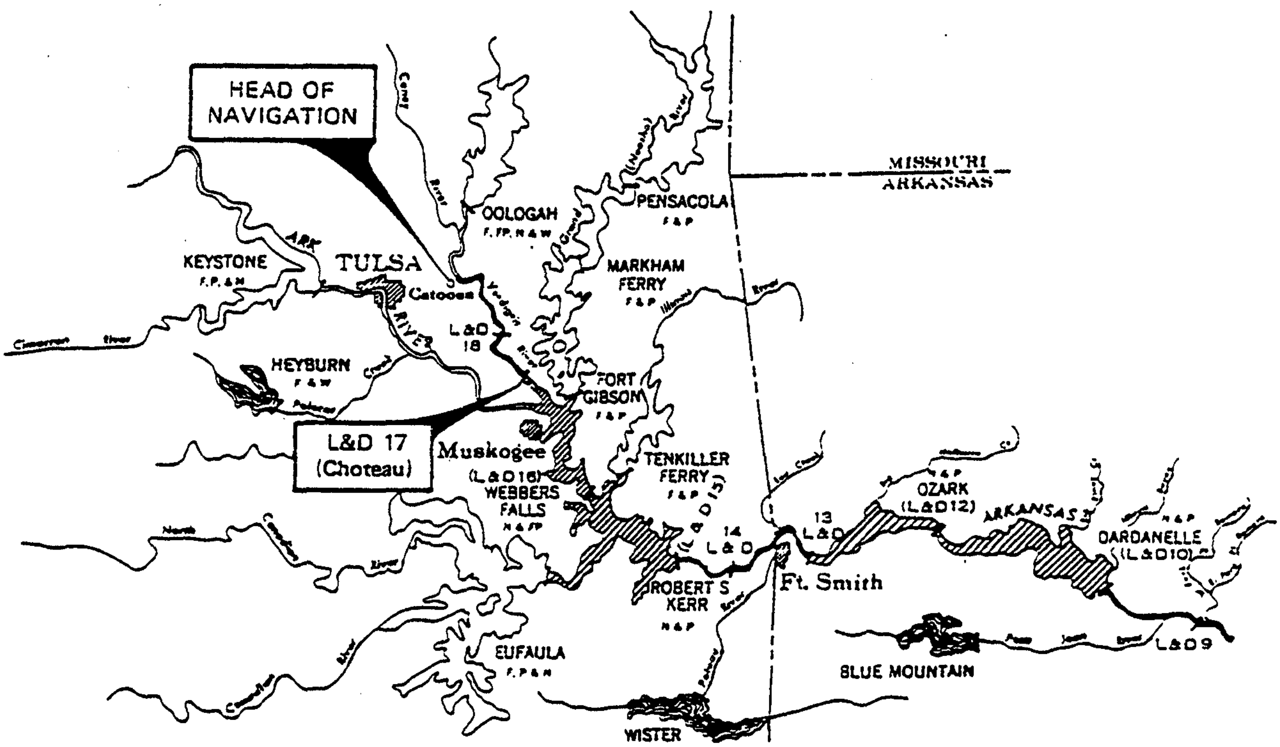
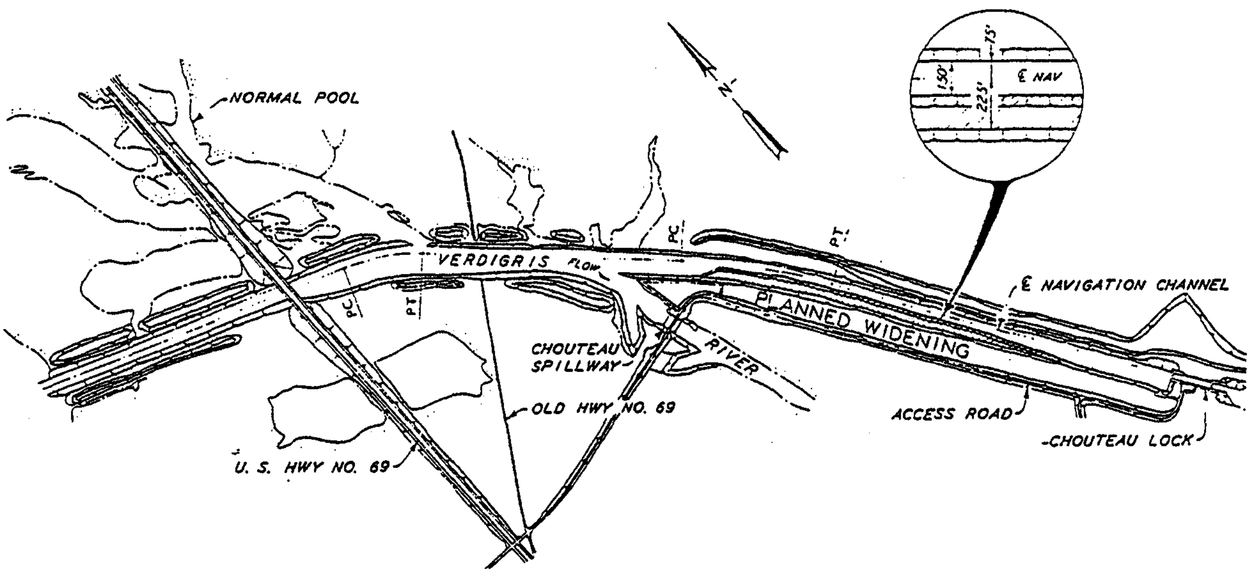


Figure 9.18. Effect of air venting on culvert roof pressures downstream of culvert filling valves, Bay Springs Lock (Ables, 1978).



a. General map.



b. Project layout.

Figure 9.19. Location Maps, Lock and Dam 17, Arkansas River Navigation Project (Huval, 1980).

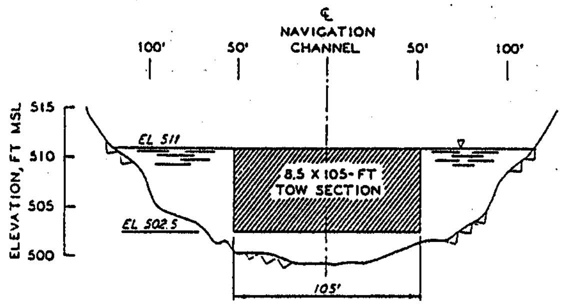


Figure 9.20. Tow in canal, Lock and Dam 17, Arkansas River Navigation Project (Huval, 1980).

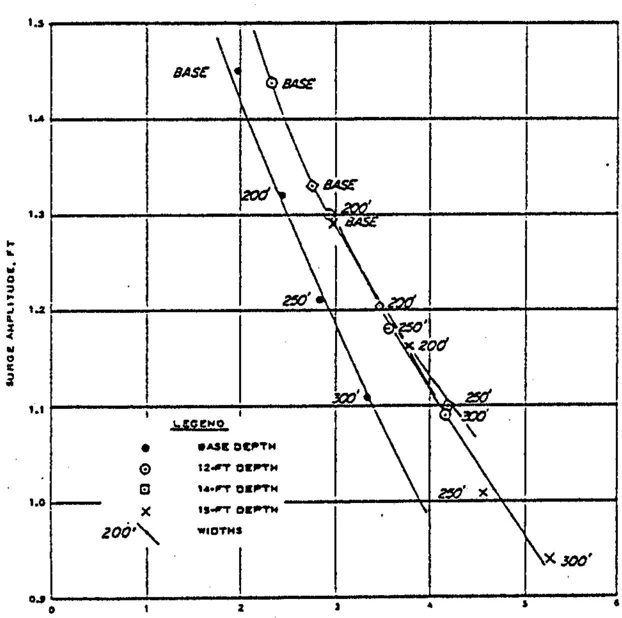
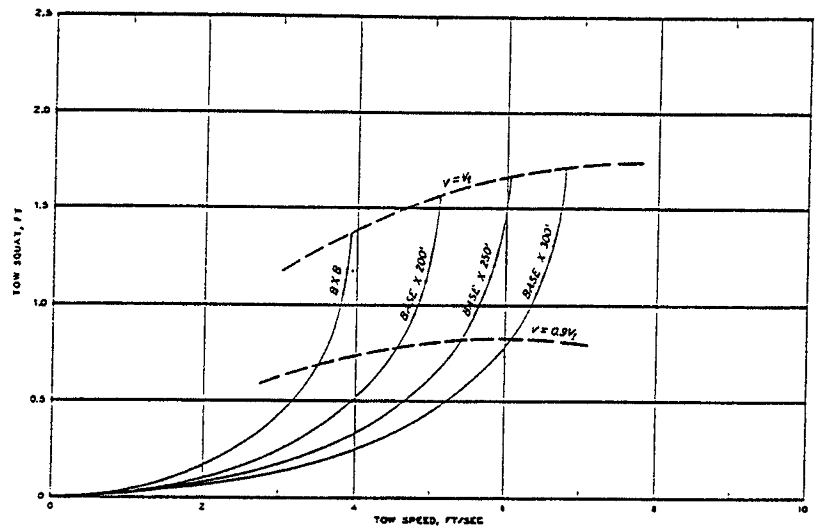
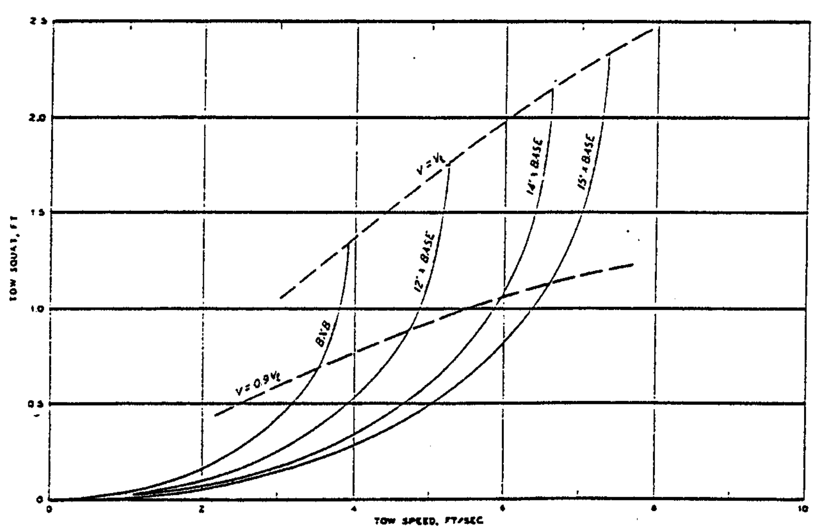


Figure 9.21 Maximum computed surge magnitudes at upstream end of transition above lock (Huval, 1980).



a. Increasing width for constant depth.



b. Increasing depth for constant width.

Figure 9.22. Effect of increasing canal dimensions on tow squat. (Huval, 1980).

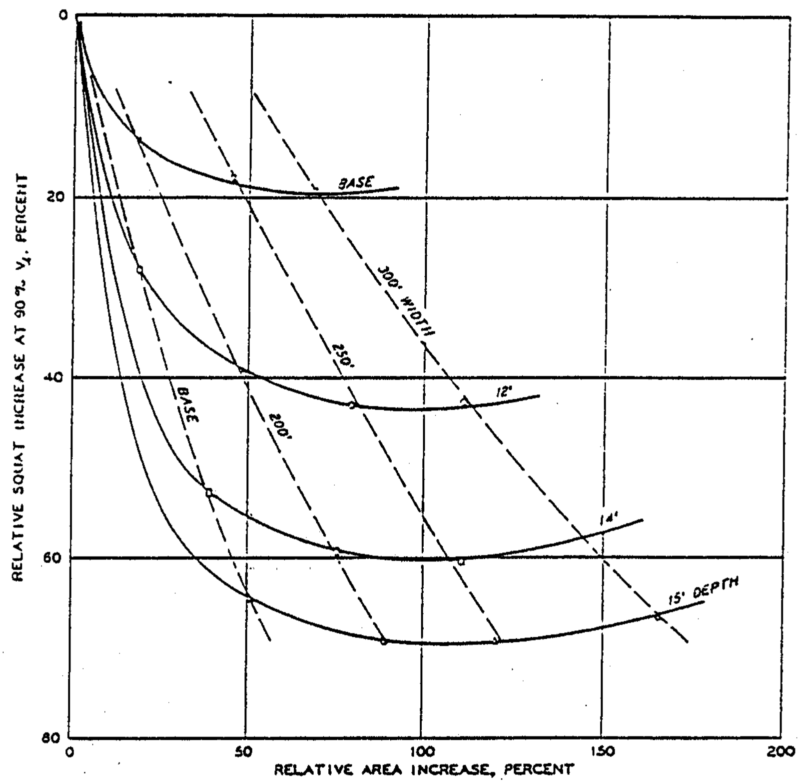


Figure 9.23 Effect of canal size on tow squat at 0.9 V_l (Huvel, 1980).

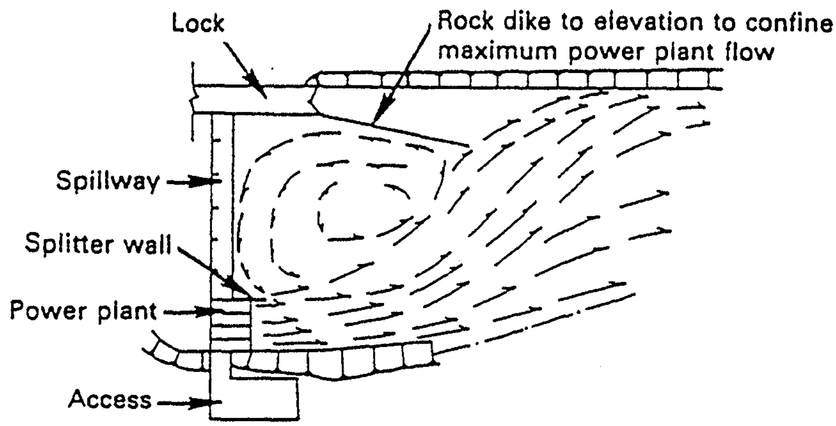


Figure 9.24. Dike to minimize effect of power plant releases on navigation in lower lock approach, Dardanelle Lock and Dam, Arkansas River (Franco, 1976).

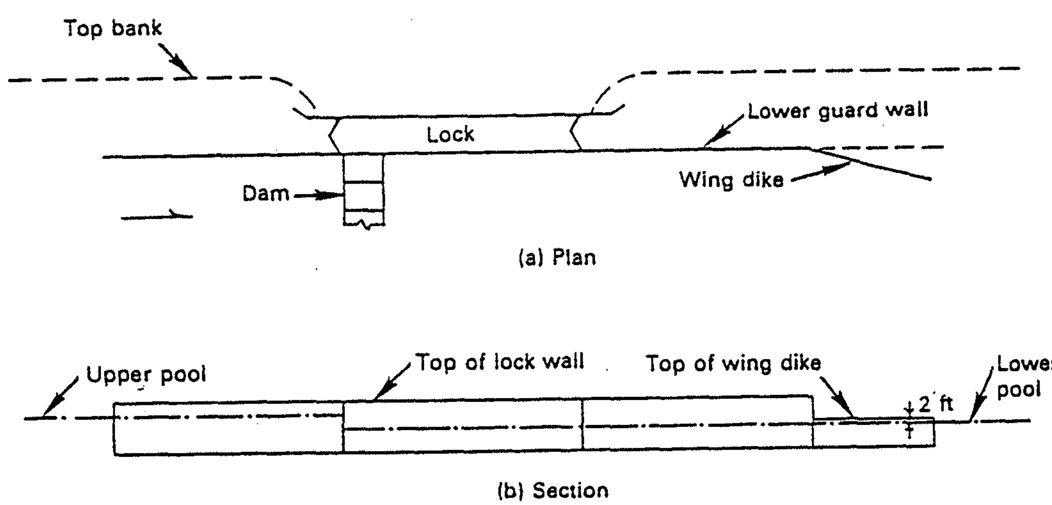


Figure 9.25. Wing dike to minimize shoaling in lower lock approach, Dardanelle Lock, Arkansas River. (Franco, 1976).